THE GOALS OF SCIENTIFIC RESEARCH

PRESIDENT'S ADDRESS READ BEFORE THE CORNELL CHAPTER OF THE SIGMA XI, MAY 17, 1915.

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Members and Members-elect of the Society of the Sigma Xi; Ladies and Gentlemen:

We are assembled tonight in order that our older members may welcome in the manner prescribed by the Constitution those who in recognition of their achievements, actual or potential, in scientific work have just been elected to membership in our Society; in order to do honor to those whom we shall henceforth be proud to designate as our fellow members in the Society of the Sigma Xi—as our Companions in Zealous Research.

Before we proceed with the simple ceremony provided by the Constitution for the initiation of new members, it is the duty of the President to explain to the initiates the aims and objects of the Society. This requirement I shall endeavor to fulfill, after amplifying somewhat the rather terse statement of our aims and objects contained in the Constitution, by briefly outlining what in my judgment should constitute the chief *Goals of Scientific Research.*

From its foundation our Society has aimed to foster the true spirit of scientific research. Its object, as summarized in Article I, Section 2 of the Constitution is "to encourage original investigation in science, pure and applied, by meeting for the discussion of scientific subjects; by the publication of such scientific matter as may be deemed desirable; by establishing fraternal relations among investigators in the scientific centers; and by granting the privilege of membership to such students as have, during their college course, given special promise of future achievement." This statement may fairly be construed to imply that our function as Companions in Zealous Research is of a threefold character—investigative, social, and pedagogic.

Our first duty as members of Sigma Xi is to respond to the demand made upon us for productive scholarship. Our Society has always exercised a potent though largely unrecognized influence in upholding the idea that in University circles the teacher of science should be not merely a distributor or disseminator, but also a producer or discoverer of the truth. The successful teacher of science,

pure or applied, must be held in his orbit by the combined action of the centripetal force of thorough scholarship and the centrifugal force of original research.

In the second place, it should be our aim to effect, through the medium of our meetings both formal and informal, and through the medium of our personal friendships, the closest possible coördination among the numerous scientific interests represented by our members. The very diversity of these interests should insure, once they are brought into appropriate relations with each other, a solidarity of organization that should lead to a clearer and wider vision of the truth for each of us.

A third responsibility, which rests especially upon those of us who are teachers, is that of participating not merely in the work of scientific investigation but also in the work of training scientific investigators. It would be difficult to overestimate the importance of this latter process. If we consider that the two great functions of the University are those of teaching and investigation, using the term investigation now to include productive scholarship in all departments of work, then in training investigators or productive scholars we are in effect bringing these two functions into simultaneous exercise. The armed forces of the University march into the Land of Ignorance, into the Territory of the Unknown, on two main lines of advance: the line of pedagogy, and the line of research. The intersection of these two roads is undoubtedly one of the most important strategic points along the entire front.

Or, changing the figure, and looking upon the University as a great manufacturing plant, we find its two chief products to be: men, and research. Now when the University succeeds in training a man capable of following the career of the true scientific investigator, a third product, which virtually combines the characteristics of the other two, is obtained. And possibly it may not be going too far to suggest that the trained investigator is, in a sense, the *main* product of the various scientific activities of the University, while research itself, however important and useful, partakes more of the nature of a necessary by-product. In view of the importance of the process of training men in research, which I think none will deny, it is a source of gratification to find that our Society makes provision for the recognition of undergraduates who have passed through the first stages of their training as investigators, and who have "given special promise of future achievement."

Let us now turn to the topic chosen for our brief consideration this evening: *The Goals of Scientific Research.* It is not my purpose to discuss the various motives that should or should not actuate the individual scientist—that should or should not serve as the inspiration of his work. Nor shall I speak of the nature, scope, or method of research. These topics have been ably disposed of by several of my distinguished predecessors in their Presidential addresses during the past few years. I would simply raise the question: Whither does Science lead us? To those engaged in the pursuit of science this question both in its individual and in its larger social aspect should be of considerable interest.

Perhaps the most conspicuous, and certainly in the popular mind the most important goal of Science and of Scientific Research is *the increase in the control exercised by man over his material environment.* "But," you say, "this spells Applied Science!" Yes, I even venture so far as to say that one of the very important functions of science is to supply inspiration to industry. Pure science, until it is incarnated in industry, is but little met with in the ordinary walks of life; while industry, until it has been enlivened by something of the spirit of pure science, is sordidly empirical. This mutual relationship—or symbiosis, as it might be called—between science and industry has reached under present conditions so advanced a stage of development that scientific investigators working in the large research laboratories of industrial corporations not infrequently make discoveries of great value to pure science. A notable instance of this sort occurred quite recently in the Research Laboratory of the General Electrical Company at Schenectady, where Doctor Langmuir in the course of his investigations upon the tungsten lamp discovered an active modification of hydrogen. Thus industry sometimes pays dividends on investments of pure science in currency that is legal tender even in scientific circles!

Instances of this sort might be multiplied. There is certainly no inherent reason for the antagonism that has appeared at times to exist between pure science and industry. There is no need for the mutual distrust with which each has now and then regarded the other. When haughty science, peering out into the world from her cloistered retreat, shall come to realize that there is need for something of her idealism in ordinary life, and when her more matter-of-fact sister, industry, learns to bow reverently with her at the inner shrine of truth, then shall true harmony be established. The

main reason for discord in the past has been, in my opinion, the comparative lack, in the ranks of industry, of men thoroughly imbued with the scientific spirit, and willing to make personal sacrifices in order to extend the kingdom of truth. The question might well be referred to our own Society, which, as we have heard, aims "to encourage original investigation in science, pure and applied," and which should aim more and more to encourage the training of men for research in the fields of science and industry alike.

Yet it is not to be inferred that the relationship between science and industry is so close that the scientific investigator should, as a rule, have in mind some possible application of his work. This would indeed be a short-sighted policy! For the history of science is replete with instances in which purely scientific discoveries have led to entirely unexpected practical applications.

But science does not merely offer to man the increased control over his material environment obtained through industry. It offers that which is of vastly greater import to his inner life—an ever-widening mental horizon. A second goal of science and scientific research is therefore *the bestowal upon man of a broader vision of the truth,* of a clearer and more accurate world-picture. Let us now briefly review in outline a few of the steps of progress made in this direction.

In the first place our conception of the magnitude of the universe—of its extent in space—has been greatly enlarged[1]. In 1543, Copernicus, by giving the death-blow to the Ptolemaic system of astronomy, with its geocentric conception of the universe, helped to prepare the way for the work of our modern astronomers whose colossal telescopes enable our vision to penetrate into regions of the universe inconceivably remote.

Secondly, our conception of the duration of the Universe—of its extent in time—has been wonderfully magnified. Thanks to the researches of geologist, paleontologist, and archeologist, alike, no scientist of the present day believes that the Universe was set in operation by special creative fiat six thousand years ago, as maintained by tradition. The great antiquity of the earth and of man himself, has been well established.

And yet, strangely enough, even while we are contemplating the great extension of our Universe in space and in time, and are try-

[1] See *Christian Faith in an Age of Science* by William North Rice, pages 15 et seq. A. G. Armstrong and Son (New York).

ing to grasp the full significance of these two concepts, the thought comes to mind that science during the last few decades has been planning a surprise for us. Yes, in spite of her efforts to present to us the loftiest view of space and time she seems to have entered into a conspiracy with invention and industry to free us, so far as possible, from their limitations. It is surely obvious that the introduction of speedier methods of transportation virtually enables us to conquer, to a certain extent, both space and time. And so with the means for bringing into close auditory communication persons in widely separated localities; for perpetuating fleeting vocal impressions and permitting their frequent repetiton long after the cords that produced them have been forever silenced; for reproducing visually at will complex series of motions, allowing the crystal to form, or the rose-bud to blossom in the thousandth part of its normal period;—all of these processes involving the use respectively, of railroad, steamship, aëroplane, telephone, phonograph, and kinetograph, those marvels of recent years—strike from our hands, in a sense, the shackles of space and time. And does this not lead us in our moments of vision, to wonder whether science is not—all unconsciously, perhaps—moving in such a direction as to bring so far as possible Man's material environment—his outer world—into harmonious relationship with his mental environment, that inner, metaphysical world in which space and time are said to be unknown, and in which location is determined by state of mind, and time is replaced by the inevitable sequence of cause and effect? Is not science—again unconsciously—striving to express on a large scale for the race that which corresponds with the law of psychophysical parallelism for the individual? It was Thoreau who asked the question:

> "What sort of space is that which separates a man from his fellows and makes him solitary? I have found that no exertion of legs can bring two minds much nearer to one another."

But we must not digress. You have probably suspected by this time, that the second goal toward which I believe science is tending to progress might be named with the single word *philosophy.*

The desire to attempt the formulation of a world-picture of some sort seems to be inherent in the thoughtful human mind. Among the ancient Greeks the existence of a certain similarity or analogy between the universe as a whole and the individual man was

accepted as a commonplace from the time of the earliest awakening of speculative thought. Allusion to this analogy between the macrocosm and the microcosm,* as it later came to be termed, is to be found in the writings of Heraclitus, Empedocles, Plato, and Aristotle, of the Stoics and the Schoolmen as well as in the works of many mediæval and modern thinkers. In the monadology of Leibnitz, for example, the monad, or individual human soul, is deemed to contain within itself an expression of the entire universe.

Turning again to modern science, we find what at once impresses us as being, at the very least, an interesting coincidence and perhaps something much deeper. In biological science it has long been recognized that there is a certain similarity between the order of development of the individual and that of the group, or as it is usually phrased, a *parallelism between ontogeny and philogeny.* This principle admits of numerous applications. Emerson, for example, in his essay on history has called attention to the analogy between biography and history—between the life of the human individual and that of the human race. And much ink has recently been consumed by our peace propagandists in the effort to convince the nations of the earth that they should behave toward one another after the fashion of gentlemen, or better still, in the manner of various organs harmoniously working together in one great social body.

And not only in biological but also in physical science do we obtain some evidence of the analogy between the Great and the Small. With the adoption of J. J. Thomson's corpuscular theory of matter we are able to dispense with our older notions concerning the nature of the atom which we now regard as a system of concentric rings of negatively charged corpuscles rotating with an almost incredible velocity about a sphere of positive electrification. As sketched by one authority the atom takes on something of the appearance of the planet Saturn, or it may be regarded as analogous in a certain sense, with the solar system or even with the still greater stellar systems.

Of much deeper significance than this rather superficial analogy between solar system and atom, however, is the parallelism that may be observed *between the order of development of the universe and that of our knowledge of the universe.* It is well known that the story of cosmic evolution as ordinarily told begins with a chapter

*See *Encyclopedia Britannica,* 11th Ed., Vol. 18, page 381.

on *astronomical evolution.* As the result of this process occurred the individualization of the great masses of matter composing the planets comprised in the Solar System, including, of course, our own earth. Then followed an epoch of *physical evolution* during which important molecular changes, such as those attendant upon a general lowering of the temperature, took place. After the temperature of the earth had fallen to a certain point, the atoms of the various elements were able to give up, to some extent, the mad dancing into which they had been driven by the heat, and to settle down in obedience to the dictates of chemical affinity, in the form of staid and stable chemical compounds. During this period of *chemical evolution* progress toward ultimate chemical equilibrium was made, with the aid of innumerable chemical reactions.

And finally, after conditions had become suitably adjusted, Life appeared, and the long era of *biological evolution* had begun. This process has taken place in several stages, including those of *botanical and zoölogical, physiological, psychological, and sociological evolution.*

Comparing now this cosmic order with the order of the development of the sciences in the mind of man, we find that it is very much the same. If the degree to which the facts and principles of a given science may be accorded precise mathematical expression be accepted as the criterion of the completeness of that science, then it will be recognized at once that astronomy is the most nearly complete science, and that physics, chemistry, and biology follow in the order mentioned. It would seem that both in the great Cosmic Mind, as it finds expression in Nature, and in the mind of man, the various types of material aggregate are brought into equilibrium in this order: first, masses; second, molecules; and third, atoms.

A tendency to follow this same order is moreover to be observed in various other departments of activity. As a means of effecting transportation, for example, animal power has long since given way to steam, and this in turn has to a considerable extent yielded to gasoline. Now in the first instance the forces developed are merely mechanical, involving the motion of masses of matter; in the case of the steam engine the expanding molecules of steam do the work; while in the internal combustion engine the force is developed through atomic activity.

In the development of various devices for hurling projectiles upon his enemies, man has also followed the usual cosmic order. After tiring of the primitive method of hurling stones and other missiles with the mechanical force of his unaided hand, he invented the bow, the elasticity of which depends upon molecular properties; and, later on, gunpowder, the explosive force of which is developed as the result of atomic transformations.

Now while I do not pretend that these various statements offer any proof of the validity of the parallelism between macrocosm and microcosm, I would at least say that taken together, they do curiously tend to confirm the intuitive wisdom invoked by the ancients in their attempt to formulate a world-picture. And one lesson that we can learn from them is that concerning the value of analogy—kept, of course, within its proper limits—as an aid in the attainment of a broader view of the universe.

As scientific investigators we are perhaps entitled to consider ourselves as in some way related to the eye of human society. If, however, the investigators in each department of research are able to see only that which directly pertains to their own narrow interests, and do not aspire to gain some vision, however faint, of the entire universe, this eye of society is to be likened to the compound or mosaic eye of certain lower animals, with its numerous, more or less independent elements, rather than to the human eye. As the scientific investigator is led in the direction of philosophy, which we are considering this evening as the second goal of research, he gradually loses the character of a mere ommatidium, and begins to contribute, for the benefit of the race, his tiny share toward the formation of a true cosmic image. As we progress toward this goal we find that again we are in a sense rising superior to both space and time in that we are entering into affiliation with kindred minds that live, or have lived, in all places and in all ages. And not only must we at times listen to voices of the past, but also, as it were, to those of the future. With the aid of our power of scientific imagination we should make every reasonable effort to anticipate future progress, for only by so doing can we hope to produce, in our minds, a reasonably complete picture of Science as a coherent, consistent whole.

For each of us must admit, with Tennyson* that

. . . . . men through novel spheres of thought
Still moving after truth long sought
Will learn new things when I am not.

And finally there is a third goal, toward which, in my opinion, scientific research tends to lead us:—*the attainment of culture.*

Now the term culture has been variously defined, and undoubtedly access to that for which it stands is to be gained by various means. I somehow feel, however, that the character of our desires, our tastes, our affections, and our ideals has more to do with our cultural status than has the character of our thoughts and actions, important as this may be. Unless our work as scientific investigators leads us to a genuine *love of the truth* that becomes more and more akin with the passing years to a ruling passion, to the exclusion of our sordid desires for honor, fame, or wealth, we shall not have received the highest gift that it is in the power of science to bestow.

Let us then, members of Sigma Xi, do our utmost as opportunity may be accorded to us, to aid in the progress of Science toward these three goals—Industry, Philosophy, and Culture.

*"The Two Voices," *Poetical Works* (Students' Edition), page 33.